Auszug aus: Proc. of the International Symposium on Flood Defence, 20.-23.9.2000, Kassel, Germany

Risk Assessment of Coastal Defences

– An Application at German Tidal Inlets –

Stephan Mai
Dipl.-Phys.
Research Associate

Nicole von Lieberman
Dr.-Ing.
Research Associate

University of Hannover
Franzius-Institut for Hydraulic, Waterways and Coastal Engineering
Nienburger Strasse 4, D-30167 Hannover, Germany
Tel.: +49 511 – 762 4295, Fax: +49 511 – 762 4002
e-mail: smai@fi.uni-hannover.de

Abstract

The traditional design approach to coastal defence systems in estuaries, especially for dikes, is essentially deterministic. Using this deterministic design approach an assessment of the safety of coastal defence systems and risk of coastal areas is hardly possible. Therefore a probabilistic design approach using level III (calculation of failure probabilities) and IV (determination of expected loss) analysis is applied at the German coast for the two major estuaries Weser and Jade. The safety standards of coastal defence systems at the test area of Wilhelmshaven – Butjadingen – Bremerhaven are compared with respect to recurrence intervals. Changes in recurrence intervals due to climate-related changes in boundary conditions are given. For certain test areas the risk is calculated.

Keywords

Jade-Weser-Estuary – coastal defences – probabilistic design approach – risk analysis

Introduction

An advanced method to estimate the safety of coastal protection systems is the probabilistic design. Within this design different levels have to be distinguished (CUR, 1990):

Level I analysis:	The required resistance of the coastal protection system is calculated taking into account the maximum historically recorded loads (e.g. water-levels, wave attack) on coastal defences with additional safety factors. The approach is essentially deterministic.
Level II analysis:	This is the most simple approach in order to use the failure probability p (respectively recurrence interval T = 1/p) of coastal defences as a design criterion. The probability of failures is calculated assuming all loads (e.g. water-levels, wave attack) to be normal distributed.
Level III analysis:	The failure probability p introduced in the level II analysis is now calculated using the actual distribution of loads.
Level IV analysis:	Within the level IV analysis besides the failure probability p the consequences of failure are taken into account. Considering the damage C caused by failures of coastal defences (e.g. dike breach) the risk to the hinterland is calculated: risk = p x C.

The level I analysis is presently applied in the design of today´s coastal defences at the German North Sea coast (EAK, 1993). Examples of the application of the level II analysis are given in CUR (1990). An level III analysis was e.g. carried out at the British coastline by Reeve (1998). The full sequence of a level IV analysis has not been carried out so far. A first estimate for the consequences of failure, using the maximum loss as a measure, is given for Schleswick-Holstein by Hofstede and Hamann (2000). The full sequence of the level IV analysis is presented for the two major German estuaries Weser and Jade in this paper.

Level III analysis

The analysis of historic storm surges revealed that main failures of the coastal protection system occurred at the main dikes. Other coastal protection elements, like storm surge barriers, did not fail. The most important failure mechanism of dikes is wave-overtopping being the reason for most dike breaches (von Lieberman and Mai, 1999). This failure mechanism is used for the determination of failure probability introducing the following concept (Mai and von Lieberman, 2000):

$$Z = h_D - Thw - R \tag{1}$$

$$R = 0.75 \cdot \gamma \cdot \frac{1}{n_D} \sqrt{g \cdot H_s} \cdot T_m \tag{2}$$

$$\frac{1}{T_{Z<0}} = p_{Z<0} = \int_{-\infty}^{0} p_{Z(Z)} dZ = \int_{-\infty}^{\infty} \int_{h_D - Thw}^{\infty} p_{(Thw,R)} dRdThw \tag{3}$$

with:

Z	reliability function respectively limit state function
h_D	height of the dike
Thw	tidal high water-level
R	wave run-up
γ	reduction factor describing the effect of slope roughness, shallow fore shore, berm and oblique wave attack.
$1/n_D$	slope of the dike
g	acceleration of gravity
H_s	significant wave height
T_m	mean wave period
p	probability of tidal high water-levels and wave run-up respectively reliability function
$p_{Z<0}$	probability of failure

The probability analysis requires knowledge of the probability distributions of load parameters. The probability distribution of some parameters like tidal high water-levels can be derived directly form measurements. Nevertheless long-term data sets are e.g. not available for wave parameters and wave run-up. Therefore the statistics of these parameters were derived from wind statistics using numerical simulations. Figure 1 shows a result of the numerical simulation relating a certain water-level (5 mNN) and wind condition (28 m/s, 330°) to significant wave heights within the test area “Wilhelmshaven – Butjadingen – Bremerhaven”. A detailed description of the numerical modelling is given by Mai et al. (2000).

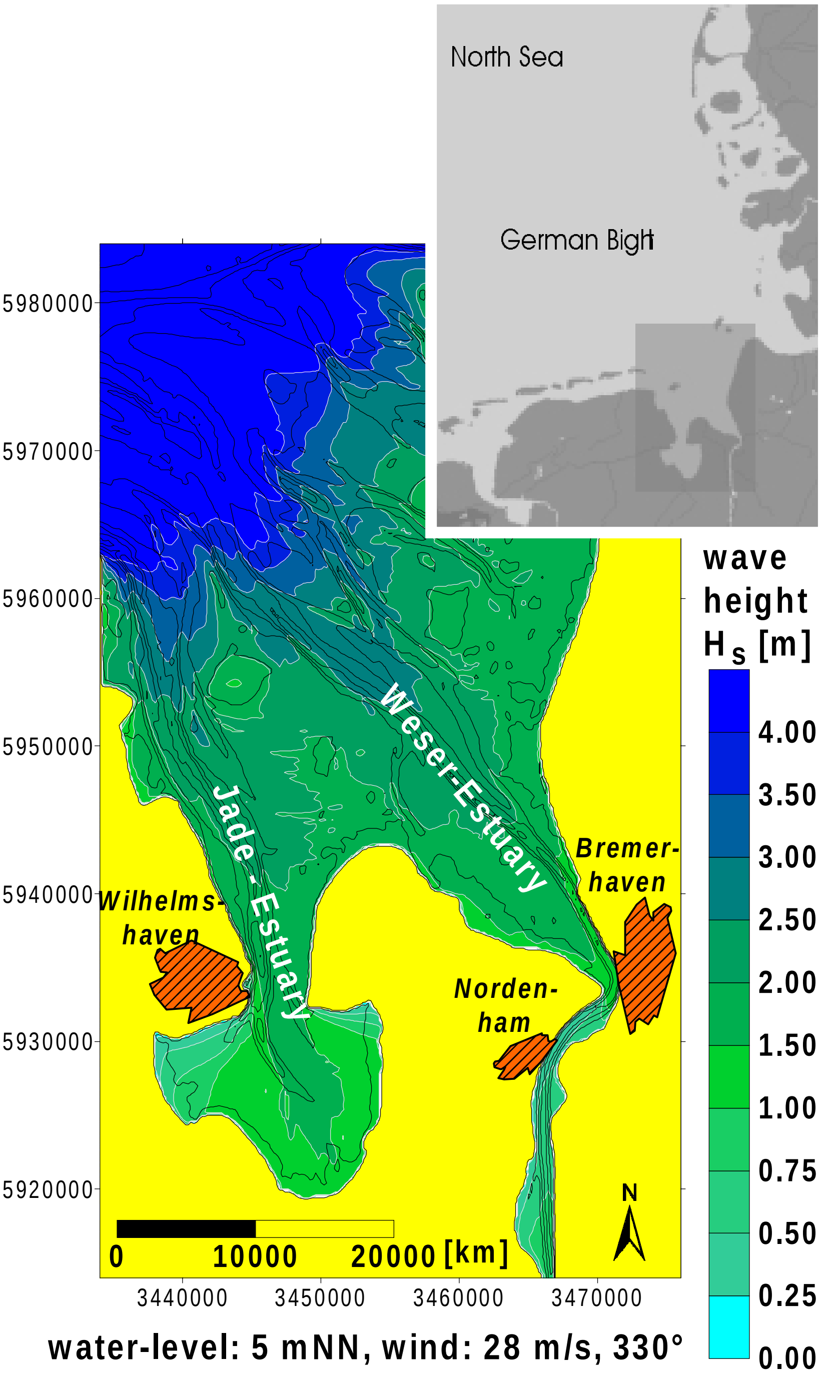

Fig. 1: Result of the numerical simulation relating water-levels and wind conditions to wave height

Examples of the statistics of the basic probability distributions of boundary conditions are given in figures 2 and 3. Figure 2 shows the distribution of tidal high water-levels for today's situation and for different scenarios of sea-level rise e.g. caused by climate change. The scenarios of sea-level rise correspond to the expected doubling atmospheric CO_2-concentration and were developed by von Storch and Reichardt (1997). A 0.50 m rise is assumed to be most probable within the next 100 years.

The probability density functions of water-levels were extrapolated assuming an exponential behaviour.

Figure 3 shows the scenarios of the wind distribution for a wind direction of 300°. For this direction the scenarios were calculated assuming an increase of mean wind velocity of 3.8% respectively 10%, while the directional dependence of the probability density remains unchanged. The extrapolation of wind statistics was done using a Weibull-distribution (Troen and Petersen, 1990).

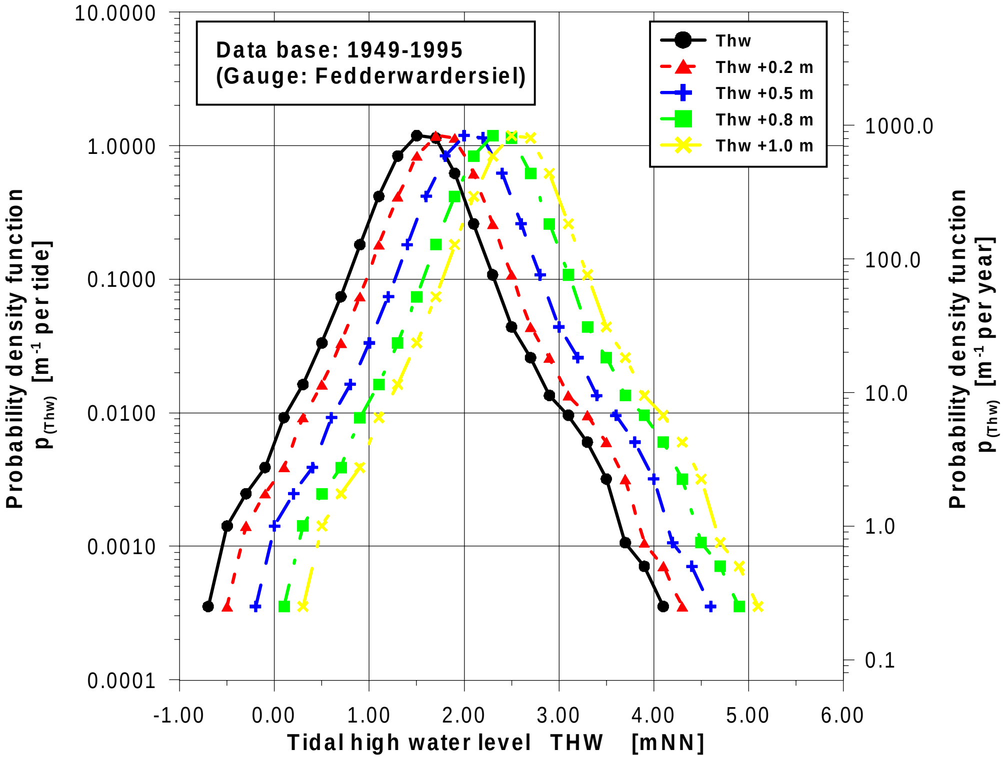

Fig. 2: Scenarios of probability density functions of water-levels

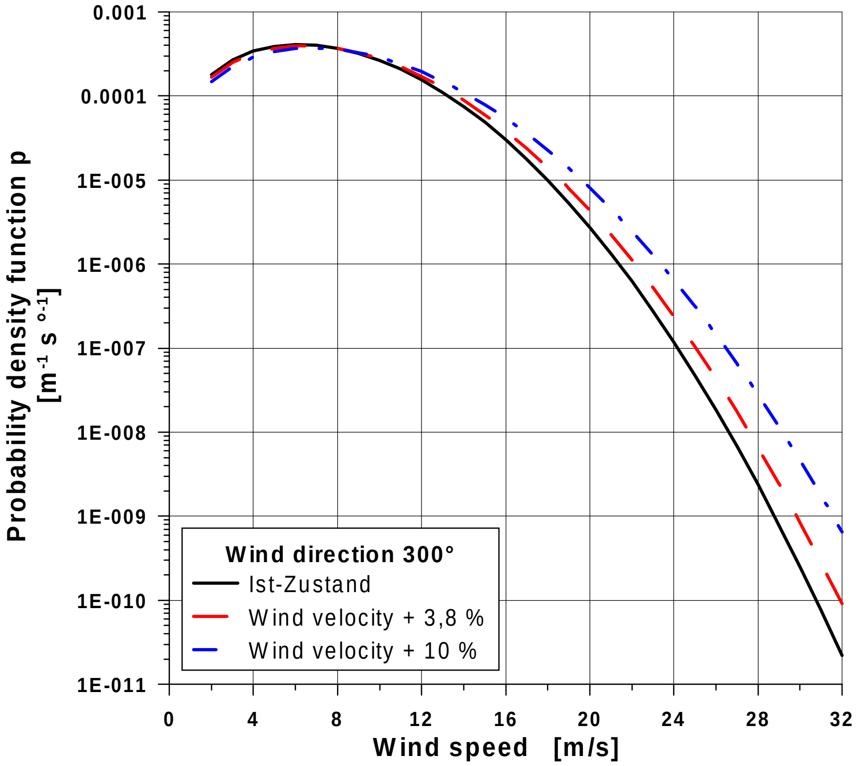

Fig. 3: Scenarios of probability density functions of wind

Using the method of level III analysis described in equation (1) to (3) the recurrence interval T (i.e. the inverse of the failure probability $p_{Z<0}$) was calculated for the different scenarios of water-level rise (fig. 4) and increased wind speed (fig. 5). Figure 4 shows the recurrence interval of failure at different dike sections P1 to P5. The recurrence interval is approximately 1,000 years for today’s situation and will be reduced to 100 years in case of a water-level rise of 1 m. In case of an increase of the mean wind velocity of 3.8% the recurrence interval remains almost the same while it decreases to approximately 900 years in case of a 10%-increase of the mean wind velocity (fig. 5).

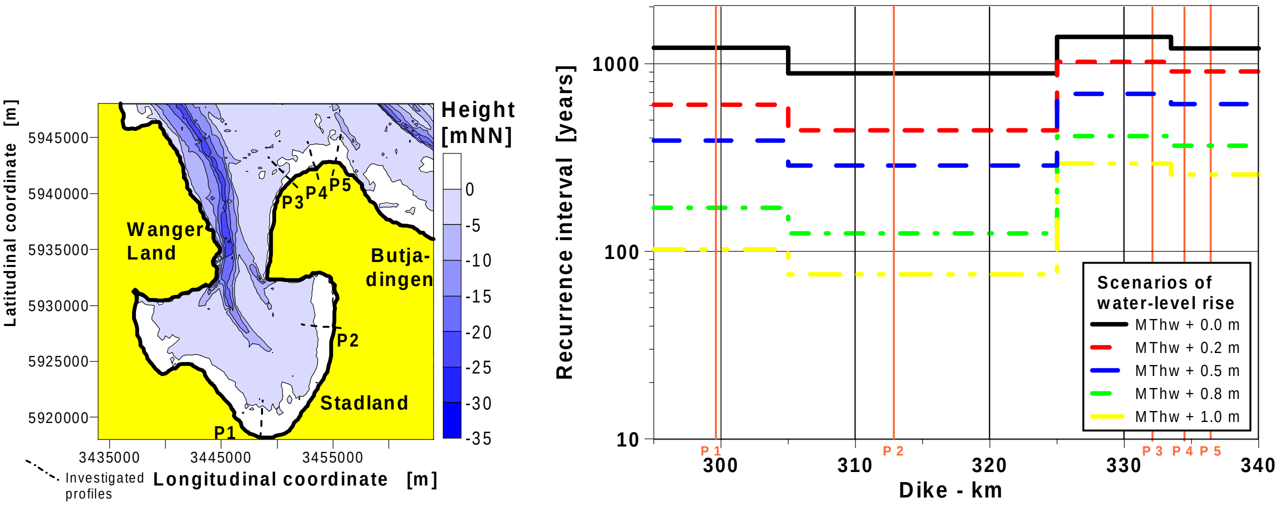

Fig. 4: Recurrence interval of wave overtopping at the main dike in case of sea-level rise

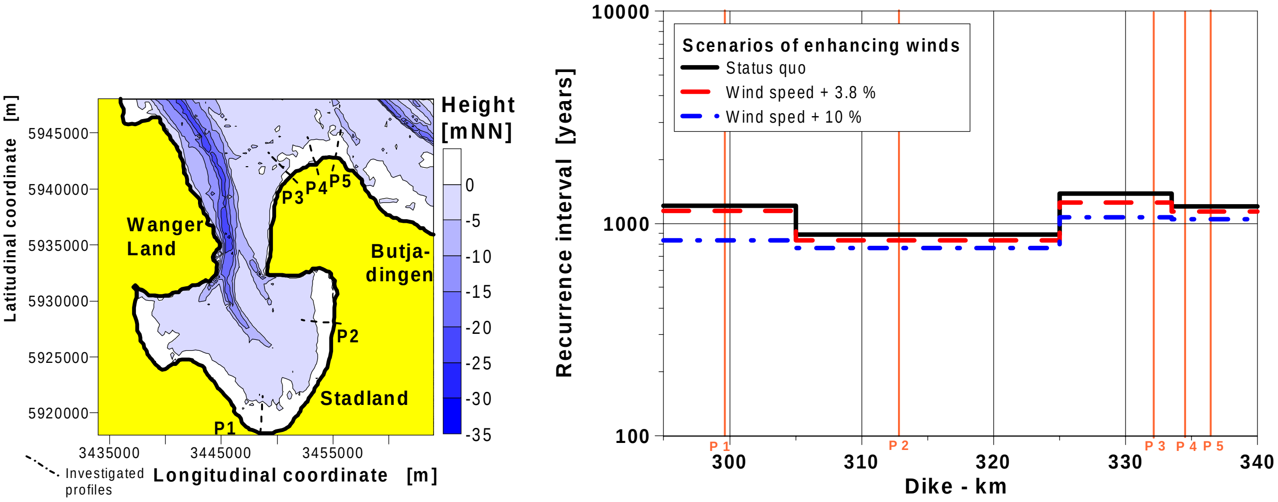

Fig. 5: Recurrence interval of wave overtopping at the main dike in case of increasing winds

The results presented in figures 4 and 5 depend on the type of distribution assumed for extrapolation to higher water-levels (larger than 4.50 mNN). As shown in figure 6 the distribution type has large influence on the probability density. The exponential distribution and the Gumbel distribution lead nearly to the same values of probability density, while the normal (Gauss) distribution gives lower and the Weibull distribution gives higher values (see Mai and Zimmermann, 2000). The effect of the distribution type on the recurrence interval of wave-overtopping at the dike section P2 is shown in figure 7. For today’s situation (no sea-level rise) the recurrence interval varies from 500 years for the Weibull distribution to 4,000 years for the Gauss distribution. The influence of distribution type decreases with increasing sea-level rise.

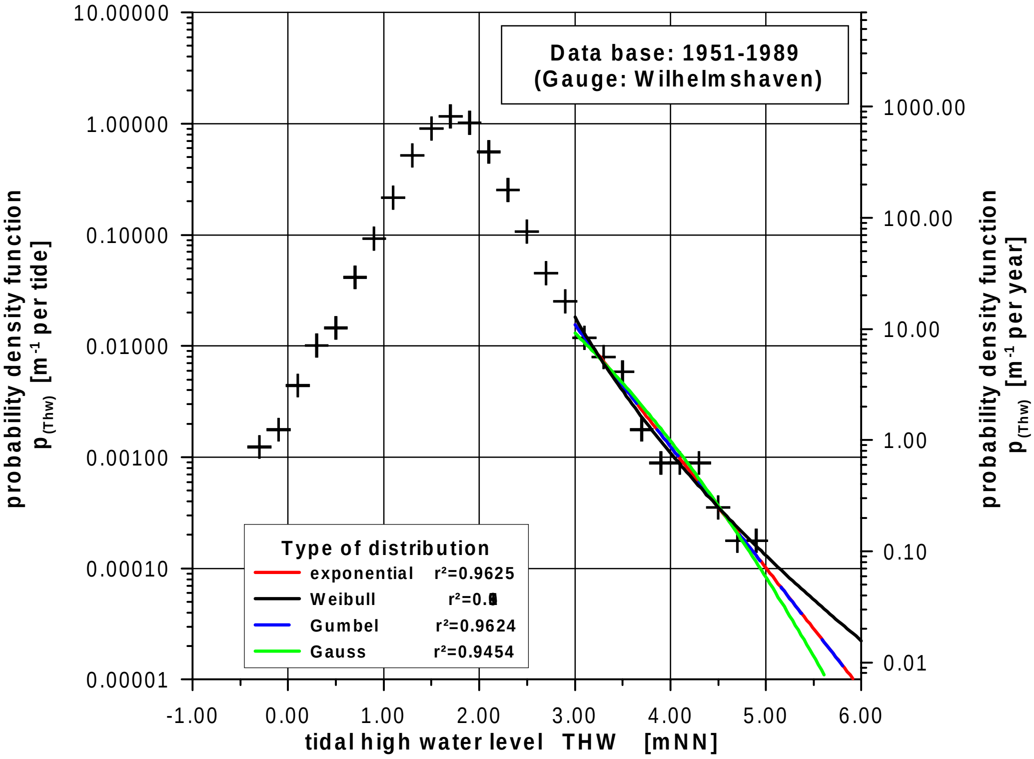

Fig. 6: Probability density function of water-levels

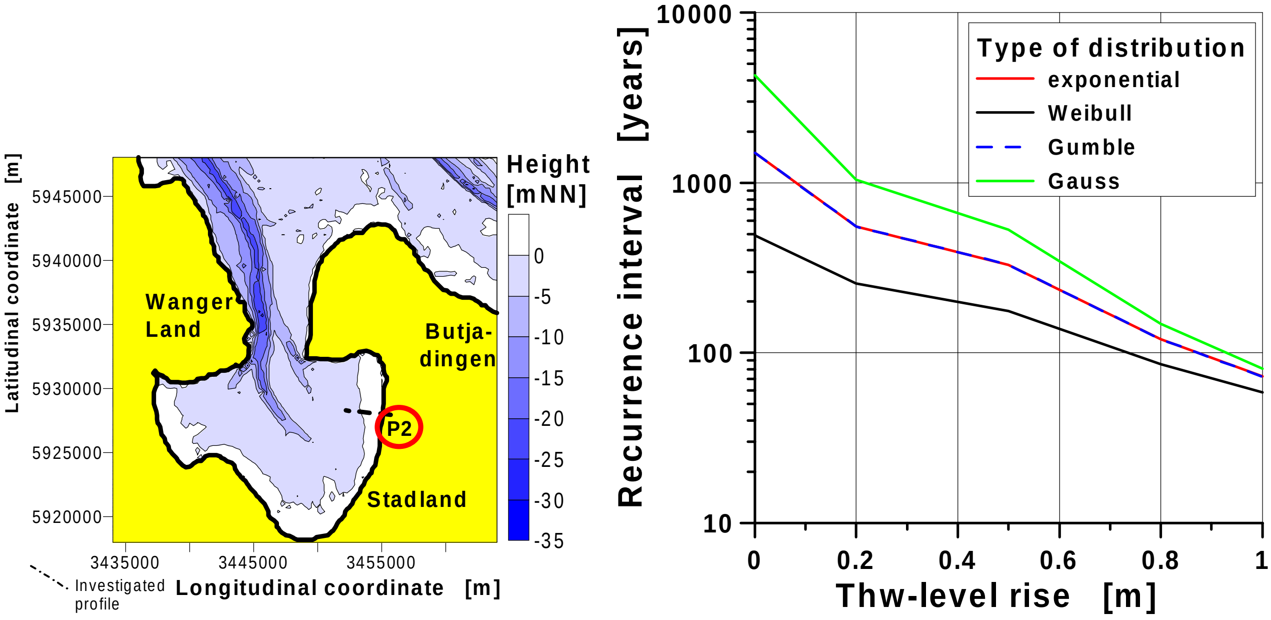

Fig. 7: Recurrence interval of wave overtopping at the main dike using different extrapolations of the statistics of tidal high water-levels

Level IV analysis

In addition to the calculation of the recurrence intervals the consequences of failure were considered. The following approach was used:

$$\text{risk} = \int_{Z<0} p_{(Z)} \cdot C_{(Z)} dZ \qquad (4)$$

$$C_{(Z)} = \varphi_{(Z)} \cdot C_{tot} \qquad (5)$$

with:

$C_{(Z)}$	actual damage
$\varphi_{(Z)}$	damage factor
C_{tot}	maximum loss

To estimate the total costs a Geographic Information System (GIS) was set up comprising information on the loads and structure of the coastal defence elements as well as on land usage and economic parameters. The information system was programmed using ArcView. The screenshot (fig. 8) shows a topographic map of the economically most relevant and the most populous (fig. 9) part of the hinterland. A part of the functionality of the GIS providing information on the coastal defence elements is shown by the photography of the lock “Fischereihafenschleuse” in Bremerhaven.

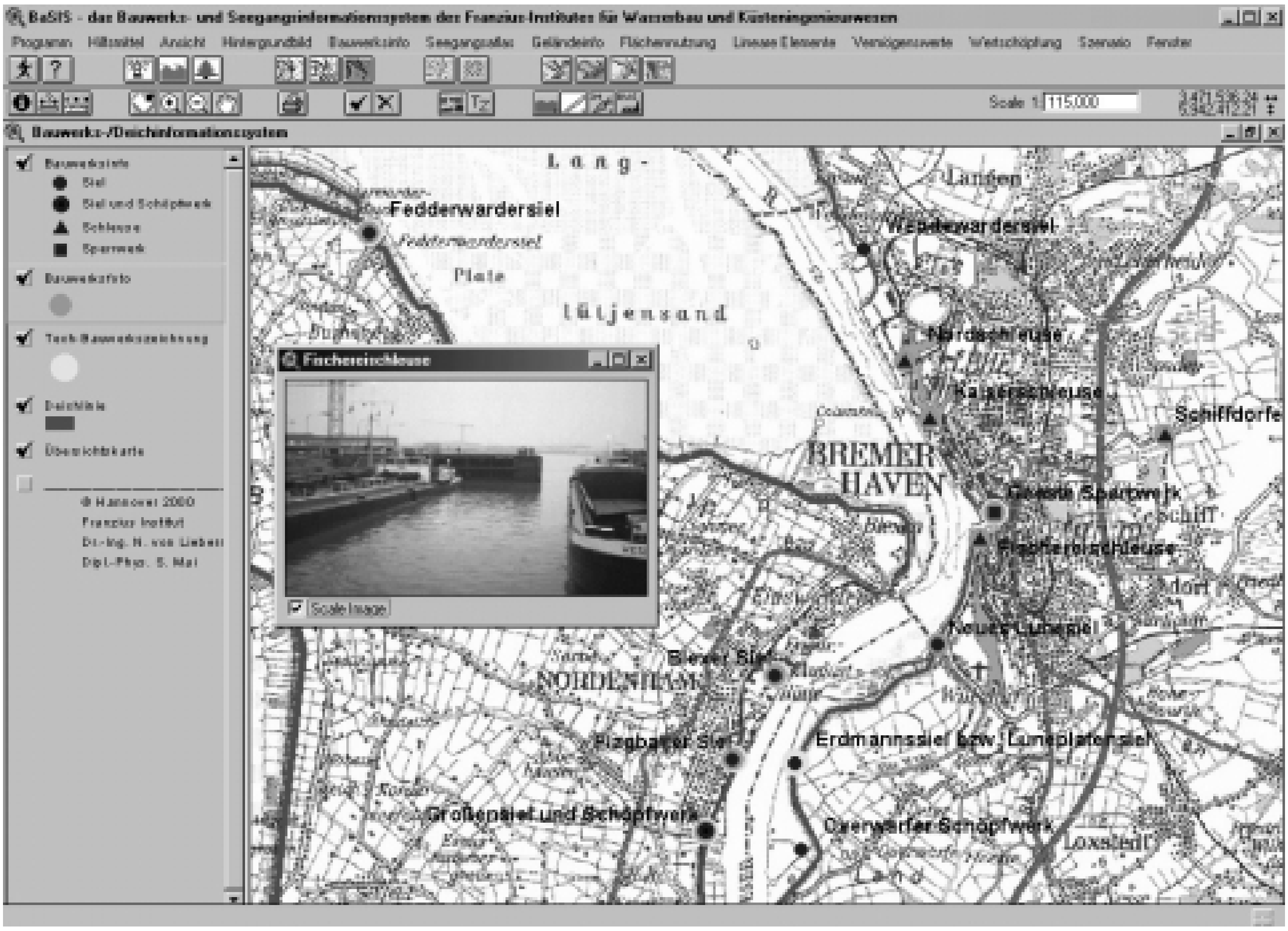

Fig. 8: Screen-shot of the Geographic Information System (GIS)

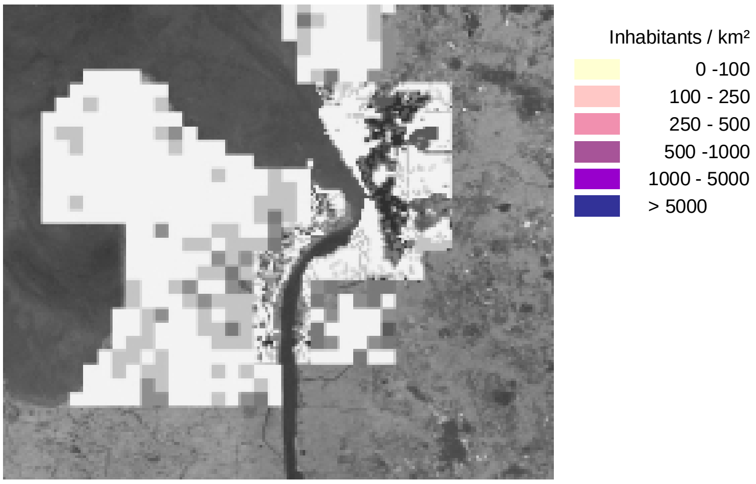

Fig. 9: Distribution of inhabitants within the test area

The maximum loss in case of a failure of a coastal protection element was calculated with numerical simulations of the inundation process. Figure 10 shows an example of this simulation using the FD-model MIKE21-HD in case of a failure of the storm surge barrier “Geestesperrwerk” in Bremerhaven. The flooded area is coloured in blue. Integrating values in this area the maximum loss was calculated. The water depth of the flooded area varies due to different topographic heights of the hinterland and in dependence of the distance from the location of failure. The actual damage was calculated using equation (5) taking into account the flooding depth and flooded area and a damage factor. Thus the risk of the selected area was calculated (see Mai and von Lieberman, 2000).

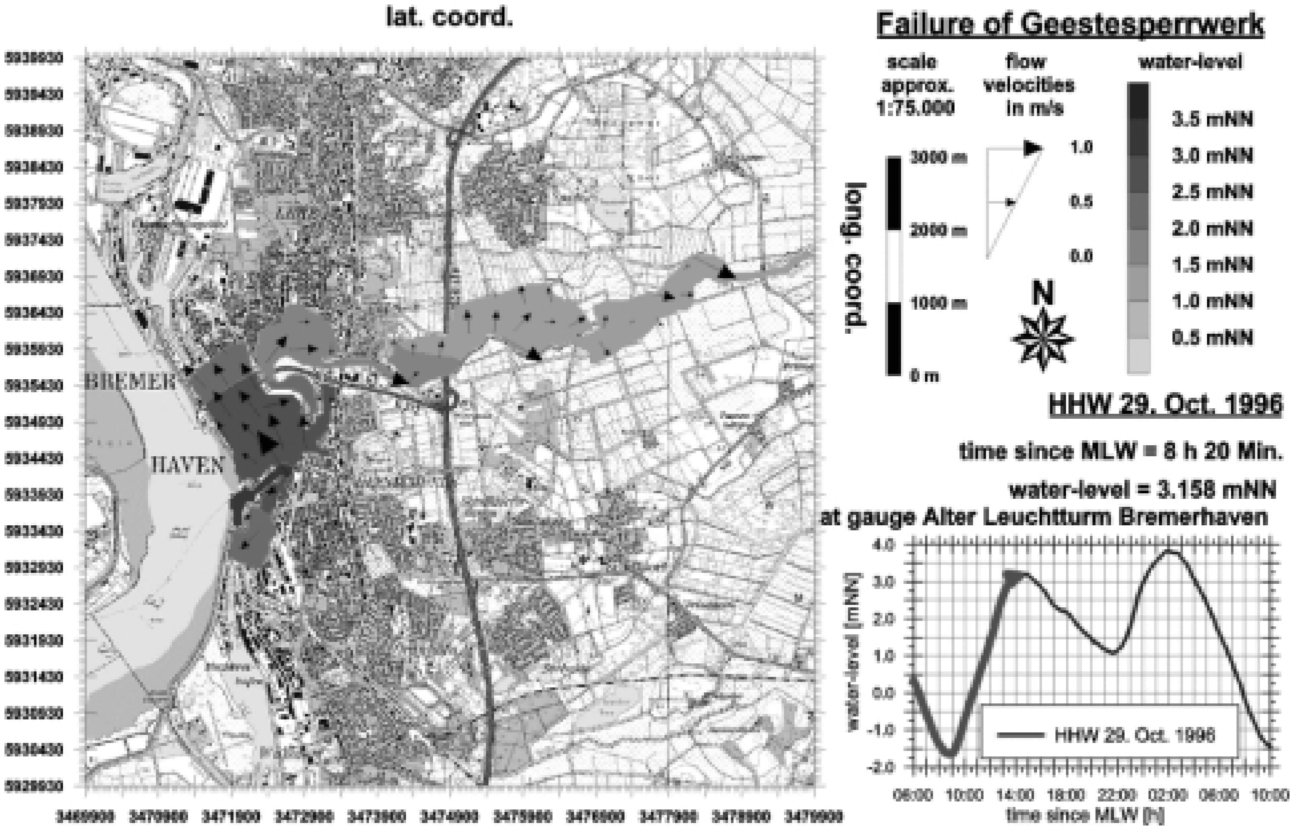

Fig. 10: Example of a numerical simulation of the inundation process in case of a failure of the storm surge barrier “Geestesperrwerk” in Bremerhaven

Conclusion

The application of probabilistic design methods reveals the influence of climate changes on coastal safety, e.g. the recurrence interval of wave overtopping at main dikes is reduced to approximately 40 %. Besides that a risk analysis shows the different vulnerability of coastal hinterlands and provides a means to include possible losses into design processes. Both aspects are neglected in today's design of coastal flood defences but will be of more importance in a future more economically balanced design.

References

Centre for Civil Engineering Research and Codes (CUR), 1990: Probabilistic Design of Flood Defences. Technical Advisory Committee on Water Defences (TAW), Report 141.

Empfehlungen des Ausschusses für Küstenschutzwerke (EAK), 1993: Empfehlungen für Küstenschutzwerke, Die Küste, H. 55.

Hofstede, J. and Hamann, M., 2000: Wertermittlung sturmflutgefährdeter Gebiete in Schleswig-Holstein. Mitteilungen des Franzius-Instituts für Wasserbau und Küsteningenieurwesen der Universität Hannover, H. 85, Hannover.

v. Lieberman, N. and Mai, S., 2000: Risikopotentiale für Nutzflächen und Infrastruktur. Mitteilungen des Franzius-Instituts für Wasserbau und Küsteningenieurwesen der Universität Hannover, H. 85, Hannover.

Mai, S. and v. Lieberman, N., 2000: Internet-based Tools for Risk Assessment for Coastal Areas. Proc. of the 4th Int. Conf. on Hydroinformatics - 2000, Iowa, USA (in press).

Mai, S. and Zimmermann, C., 2000: Risk Analysis of Coastal Protections at Tidal Coasts. Proc. of the 2nd Int. Conf. Port Development & Coastal Environment, PDCE - 2000, Varna, Bulgaria (accepted paper).

Mai, S. and v. Lieberman, N., 2000: Belastungen aus Wasserständen und Wellen. Mitteilungen des Franzius-Instituts für Wasserbau und Küsteningenieurwesen der Universität Hannover, H. 85, Hannover.

Mai, S., von Lieberman, N., Fittschen, T., Bartels, K., 2000: Seegang in der Weser vor Bremerhaven – ein Vergleich von Naturmessung und numerischer Simulation, Hansa (in press).

Reeve, D.E., 1998: Coastal Flood Risk Assessment. Journal of Waterway, Port, Coastal, and Ocean Engineering, No. 5.

von Storch, H. and Reichardt, H., 1997: A Scenario of Storm Surge Statistics for the German Bight at the Expected Time of Doubled Atmospheric Carbon Dioxide Concentration. Journal of Climate, Vol. 10, p. 2653-2662.

Troen, I. and E.L. Petersen, 1990: Europäischer Windatlas.

Figure captions

Fig. 1: Result of the numerical simulation relating water-levels and wind conditions to wave height

Fig. 2: Scenarios of probability density functions of water-levels

Fig. 3: Scenarios of probability density functions of wind

Fig. 4: Recurrence interval of wave overtopping at the main dike in case of sea-level rise

Fig. 5: Recurrence interval of wave overtopping at the main dike in case of increasing winds

Fig. 6: Probability density function of water-levels

Fig. 7: Recurrence interval of wave overtopping at the main dike using different extrapolations of the statistics of tidal high water-levels

Fig. 8: Screen-shot of the Geographic Information System (GIS)

Fig. 9: Distribution of inhabitants within the test area

Fig. 10: Example of a numerical simulation of the inundation process in case of a failure of the storm surge barrier “Geestesperrwerk” in Bremerhaven